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Needle-tissue interaction force study during simulated regional anaesthesia

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Abstract. Needle insertion usually performed with the aid of an Ultrasound (US) image in the regional anaesthesia. Getting the position of the needle tip from US requires the technical expertise and skilled anaesthetist. To detect where the needle tip is around the nerve during the needle insertion, a modified block needle attached with a force sensor is used to feedback the amount of counter force from the needle tip. This paper is to investigate whether needle force under ultrasound guidance can guide anaesthesiologists in identifying the relative position of the needle tip and nerve. The goal of our research was to use the visual needle tip force to guide the anaesthetist to detect the relative positions between the needle tip and nerve.

1. Introduction

Needle insertion was commonly used in various clinical procedures such as regional anaesthesia, brachytherapy and medicine delivery [1]. The diagnostic accuracy and operation effectiveness highly depends on the accuracy of the needle tip displacement [2, 3]. In the clinical procedure, the needles usually have to insert into deep, inhomogeneous and isotropic tissue to reach the target, however it is a clinically and technically challenge for clinical precision needle insertion because of the needle bending and tissue deformation [2]. Regional anaesthesia provides anaesthesia for limbs and allows awake surgery without consequent risks. A successful regional anaesthesia is to ensure optimal distribution of local anaesthesia around nerve structures [4], and the surgeons almost rely on the tactile feedback from the needle to guess the relative positions between the needle tip and nerve structure [5]. Complications such as unnecessary pain, tissue damage have been studied in anaesthesia [6], and injecting the anaesthesia at the adequate location is the key for regional distribution of local anaesthesia [7].

To solve this clinical challenge of precision needle insertion and infusion, the Ultrasound-guided regional anaesthesia (UGRA) imaging techniques are used to secure an accurate needle position and monitor the distribution of local anaesthetic solution in real time [8]. Multiple studies have demonstrated UGRA can improve block success rate and complication [9, 10], however UGRA has a number of limitations. Image resolution and quality vary with clinical ultrasound machines and depth of penetration [11, 12] and it was few reported that the lack of visualization of the needle tip during needle advancement may lead to the inadvertent puncture of nerve structures and fail the regional



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anaesthesia. Judging the relative positions of needle tip and nerve from the ultrasound image requires both expertise from the user and good resolution and usually requires high frequency transducers [13]. Needle insertion force was studied a lot for the interactive simulation and Robotic Percutaneous Therapy [14-16], it would be possible to improve the insertion accuracy if the visual needle insertion force could be provided to guide anaesthetist to figure out the relative positions of needle tip and nerve combined with the Ultrasound image.

In this paper, first we conducted simulated sciatic nerve blocks on lamb shanks at different sites to verify whether the Needle insertion force can predict the relative positions between the needle tip and nerve during nerve blocks. The needle insertion speed for anesthetist is around 1mm s^{-1} [3,15] and the effects of different needle insertion speeds 0.25mm s^{-1} , 0.5mm s^{-1} , 0.75mm s^{-1} , 1mm s^{-1} , and 1.5mm s^{-1} was studied secondly.

2. Material and Method

2.1. Force measurement system

A bevel 150mm 21g standard block needle (B.Braun, Sheffield, England) for regional anaesthesia was placed through an annular force sensor (LC8100-200-10, Omega, UK) as the Figure 1 shows, and force sensor and needle were clamped on a mount with three degrees (translation, rotation) of freedom motor stage (TDC001, THORLABS, US), and the motor stage can control the needle insertion speed from 0 to 2.4mm s^{-1} . The force signal cable connected with Data Acquisition System (DAQ-9174, National Instrument, US), which was interfaced to a computer running LabVIEW 2012, the force data was shown and recorded by the LabVIEW Program in sampling 1000Hz.

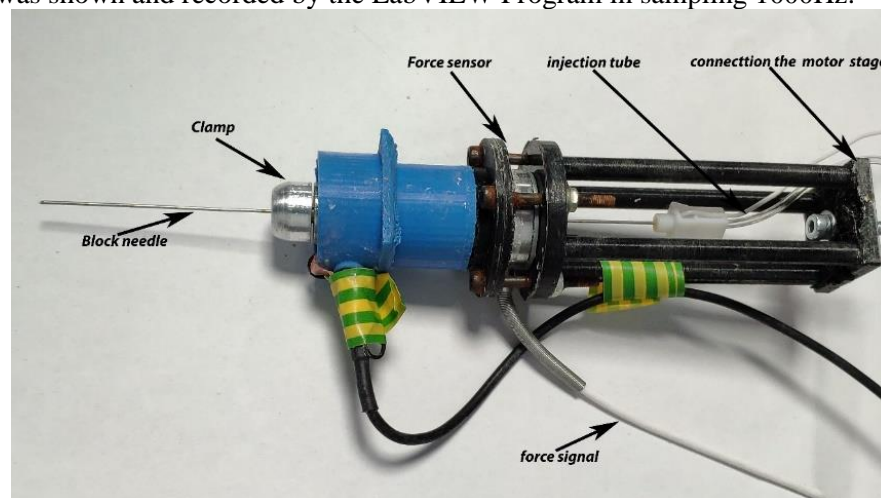


Figure 1. Special block needle with force sensor setup

2.2. Lamb shank experiment

We repeated 24 simulated sciatic nerve blocks on a lamb shank at different sites. The lamb shank experiment setup was shown as Figure 2. The needle insertion was performed under control of the motor stage to avoid the variation had this been done manually. The fresh lamb shank was put in the handed up and down stage, the needle keep the constant angle 30 degrees from the horizontal. The needle was inserted at speeds of 0.25mm s^{-1} , 0.5mm s^{-1} , 0.75mm s^{-1} , 1mm s^{-1} , and 1.5mm s^{-1} , imaged using the commercial clinical SonixTablet (BK Ultrasound, Herlev, Denmark) with an L14/5 wideband linear Probe which was held by the handed stage with three translations. We synchronize all the equipment time that could guarantee the force and image data at the same time axial.

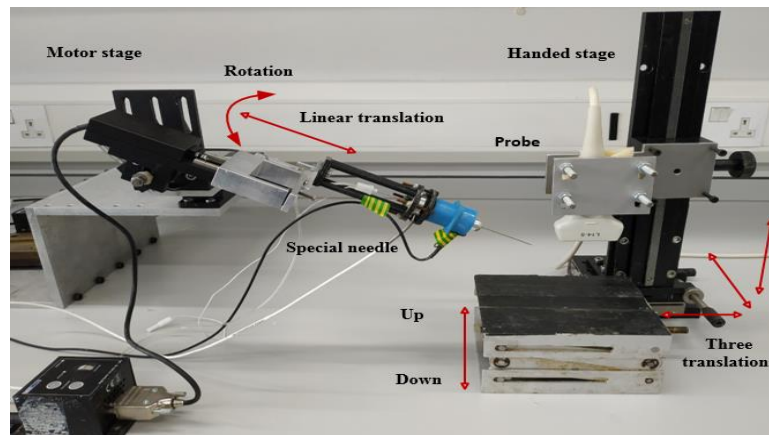
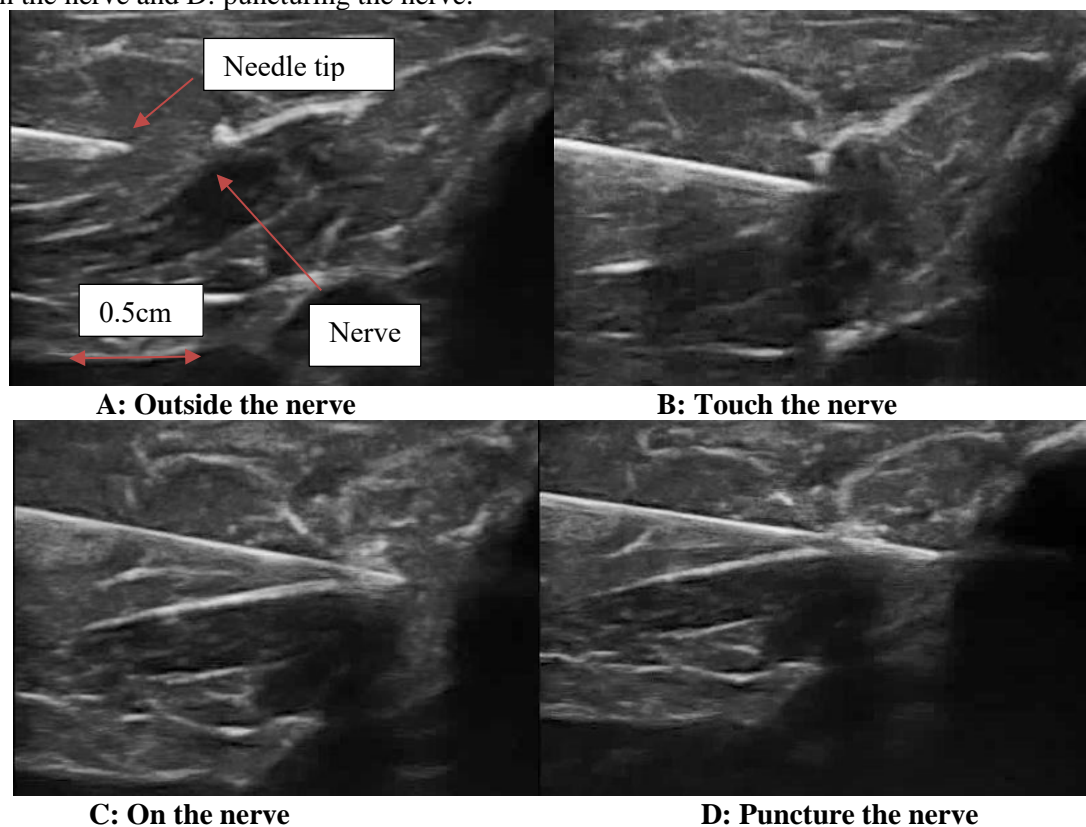


Figure 2. Lamb shank experiment setup

From the ultrasound image, the relative locations between the needle tip and nerve identified and the corresponding force value noted. The typical needle insertion procedure was divided into four distinct regions periods as Figure 3 shows: A: the needle tip outside the nerve, B: touching the nerve, C: on the nerve and D: puncturing the nerve.



C: On the nerve

D: Puncture the nerve

Figure 3. Four distinct regions periods under the ultrasound image

The Four distinct regions periods were described as follows:

A. The needle tip outside the nerve

Before the needle tip touches the nerve surface, needle has begun to insert, and we define it as the needle tip outside the nerve region period. During this period, the needle tip touches the tissues around the nerve first, the needle was inserted through skin, fascia and muscle. The injection for regional anaesthesia should conduct when the needle tip was opposed to fascia and epineurium, but it is challengeable to find the location of needle tip directly. There are many muscles and fascia around the

nerve usually, some vessels and fat sometimes, which indicates the force value change irregularly based on the different specific tissues around the nerve.

B. the needle tip touching the nerve

When the needle tip contacted the nerve surface but not have an obvious deformed for nerve, we defined it as the needle tip touching the nerve period, this period keeps a short time. Although it keeps a short time, it is important for anaesthetist to choose the right injection time, anaesthetist usually injected before touching the nerve but close to the nerve. The touch force is important time point to distinguish the A and C period.

C. The needle tip on the nerve

The needle tip on the nerve period begin from the needle touching the nerve point B to the puncture the nerve surface point D. During this period, the nerve shape deformed, the needle insertion force usually increases as the level of nerve deformation increase. We select the median time force of this period as the force value on the nerve to compare.

D. The needle tip puncturing the nerve

The needle tip puncturing the nerve period was the time the needle puncturing the surface of nerve and then inside the nerve. when this happen, it will cause damage to the nerve. We should avoid puncturing the nerve in regional anaesthesia.

The corresponding insertion force values in these four different periods were shown in Figure 4. Force values at the different periods were noted according to the high-resolution US guidance .We use the SPSS software (version 25.0, SPSS, IBM) to compare the mean force in the different speeds and different relative positions of needle tip and nerve.

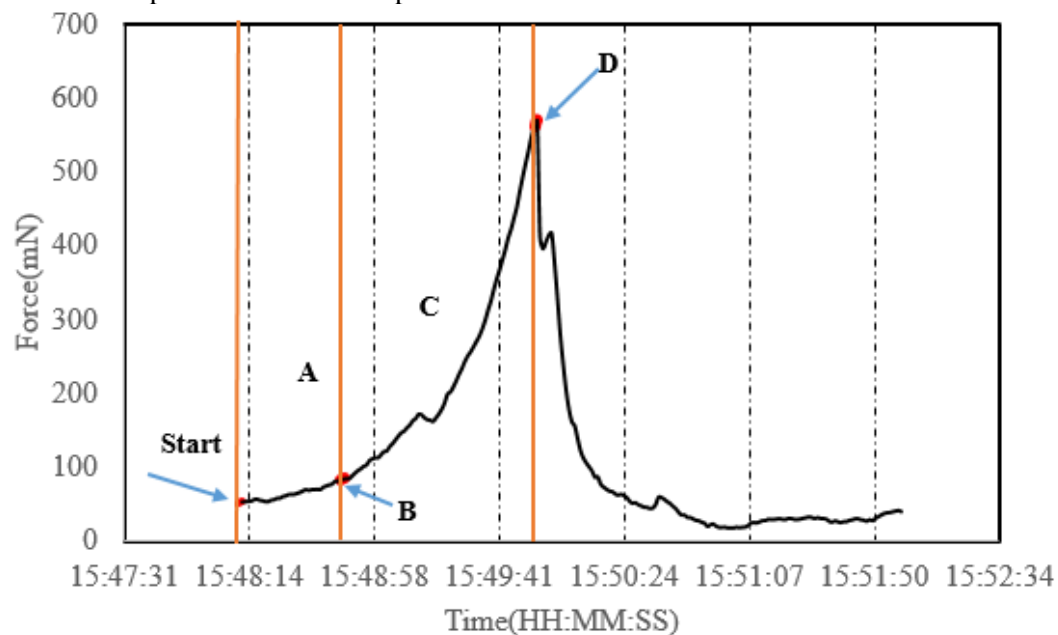


Fig.4. Insertion force change during the needle insertion process

3. Results

The force showed no significance difference between the different insertions speeds 0.25 mms-1, 0.5mms-1, 0.75mm s-1, 1mm s-1, but has significance at the speed of 1.5mm s-1. The mean force from 40 sites was differentiated at the different relative positions between the needle tip and the nerve with a significance ($P < 0.01$). The Mean force as the Figure 5 shows: the needle tip outside the nerve [189.90 ± 21.39 mN], touching the nerve [404.4 ± 39.36 mN], on the nerve [927.30 ± 80.89 mN], puncturing the nerve [1626.13 ± 137.44 mN]. The result indicates the needle insertion force can identify the relative positions of the needle tip and nerve during nerve blocks indicating nerve contact and risk of damage.

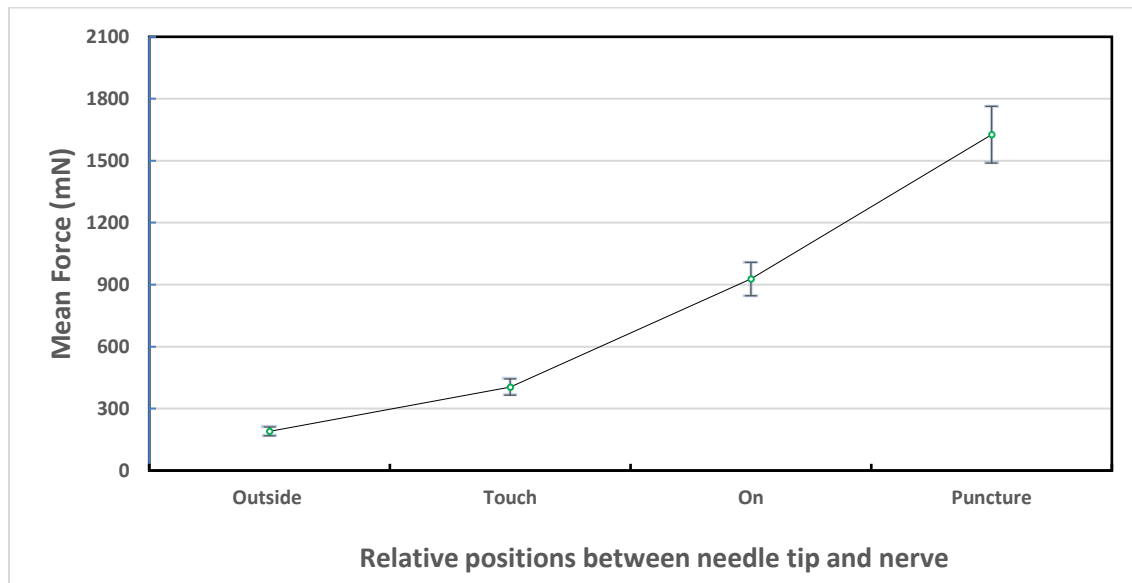


Fig.5. Force comparison in relative positions of needle tip and nerve

4. Conclusion and Discussion

From the lamb shank experiments results, the mean force value in the four relative positions of needle tip and nerve has a distinguish force range, which could help us build a needle-tissue interaction force feedback method for the simulated blocked training and guide the regional anesthesia not only using the pressure and ultrasound image guidance. The insertion speed for regional anesthesia is around 1 mm s^{-1} , and the needle insertion speed from the 0.25 mm s^{-1} to 1 mm s^{-1} shows no significance on the force value change but 1.5 mm s^{-1} , and it indicated the range of speed may have influence for the insertion force change. A bigger insertion speed range should be conducted to study the force change in tissue in the future.

In this paper, we are shortage of considering the needle deformation influence for the needle-tissue interaction force. There are still some parameters influencing the needle-tissue interaction force should be considered: needle diameter, needle tip (blunt, diamond, conical, bevel), bevel needle angle (if use bevel needle), drive mode (robot-assisted and hand-held) insertion process (interrupted and continuous). Future experiments will involve the bigger speed range, needle deflection and tissue deformation. Our over-riding aim is to use the force guidance as another remark of the needle tip positions during the regional anaesthesia.

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